158362

GEOPHYSICAL INVESTIGATION

of

SAUGET MUNICIPAL LANDFILL

FOR BURIED DRUMS

Sauget, Illinois

for

ECOLOGY & ENVIRONMENT, INC.

and

U.S. ENVIRONMENTAL PROTECTION AGENCY

Chicago, Illinois

Technos #83-118

Submitted by:

TECHNOS INC.
Consultants in
Applied Earth Sciences
Miami, Florida

TECHNOS INC. consultants in applied earth sciences

June 24, 1983

Mr. Ron St. John
Geologist
Ecology and Environment, Inc.
FIT Region V
223 West Jackson Boulevard
Chicago, IL 60606

RE: Sauget Municipal Landfill, Geophysical Survey for Drums

Dear Ron:

Enclosed are three (3) copies of our report entitled "Geophysical Investigation of Sauget Municipal Landfill for Buried Drums". Since this completes Technos' portion of this project, our invoice is also enclosed.

As you are aware, the Sauget Landfill was surveyed using a continuous output gradiometer magnetometer system along parallel traverse lines spaced at 12.5 feet intervals. For all practical purposes this constitutes nearly 100% coverage of the landfill.

The magnetometer results indicate several large areas which contain numerous magnetic anomalies; these are of sufficient magnitude and density as to be buried drums. Large quantities of buried large appliances and car bodies/engines could also be the source of these responses, but it is unlikely that such items would be found in the densities measured at Sauget Landfill.

Few areas are free of magnetic anomalies which will cause problems for your drilling program. The area of the levee embankment and selected positions north of the landfill may be possible alternatives.

Ed and I enjoyed our field collaboration with you and Jerry. If I may be of further assistance to you or Jerry, please call me at (305)634-4507.

Sincerely,

Bob

Robert A. Glaccum
Senior Scientist

RAG:vvm
Enclosures

3333 n. w. 21st street
miami, florida 33142
(305) 634-4507

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Note: BP denotes Back Pocket of report

SUMMARY

Drums containing volatile organics were uncovered during recent excavations for a railroad spur at the Sauget Municipal Landfill, Sauget, Illinois. The landfill is situated adjacent to a known hazardous waste dump and may have received similar toxic wastes. Investigation of the landfill is currently being conducted by EPA and Ecology & Environment Inc. to determine the extent of possible buried drums and leaking toxic wastes in the surrounding landfilled materials and soils. Technos Inc. has supported this effort by conducting a geophysical investigation of the Sauget Municipal Landfill primarily using magnetometry, along with electromagnetics and ground penetrating radar techniques to locate and map areas of possible buried drums.

The following significant information was derived from this survey:

1. Magnetic anomalies (intensity level 1, Figure 7) were recorded over most of the landfill which probably indicate the limits of landfilling.

2. Magnetic anomalies with greater intensity (levels 2 and 3, Figure 7) were located in several areas in the north-central and western portions of the site. These areas are delineated in Figure 7 and indicate burial areas of relatively large concentrations of steel/iron materials such as drums or car bodies.

3. The delineated magnetic variations may be caused by drum-like masses occurring at depths of 2 to 25 feet. If drums, these individual masses could represent 1 drum at a depth of 2 feet to as many as 50 drums to

depths as great as 25 feet (over a surface area of about 25 feet in diameter).

These magnetometer results were derived from 33 magnetometer lines made along parallel lines spaced at 12.5 foot intervals across the site providing approximate total site coverage. A specialized gradiometer magnetometer was used with its output continuously recorded on a strip chart.

Four ground penetrating radar and electromagnetics reconnaissance lines were also made during initial site tests. Field analysis indicated the superiority of the gradiometer magnetometer for conducting the complete survey.

BACKGROUND AND OBJECTIVES

BACKGROUND

Sauget Municipal Landfill is situated in Sauget, Illinois, a small commercial community located just south of east St. Louis. The municipal landfill is immediately adjacent to the east side of Sauget Toxic Dump which lies along the Mississippi River (Figure 1).

The landfill area is approximately 350 by 1800 feet covering some 14.5 acres. It is bounded on the west by Sauget Toxic Dump fence and on the east by a flood control levee. Three large high tension power lines extend down the length of the landfill; a buried railroad track is located along the eastern edge of the site's gravel access road. Piles of fly ash were present in the NW corner of the site. Several depressions were observed over the landfill; the largest occurring along the western fence edge (see Figure 2).

Pillsbury Corporation operates a bulk loading/unloading terminal just to the SW of the landfill (Figures 1 and 2). Recent construction of a railroad spur across the western edge of the dump uncovered numerous drums within the landfilled materials (personal communication, E & E personnel) releasing volatile organic fumes. Construction activities were consequently halted because of the obvious safety hazard.

Since both Sauget Municipal Landfill and the adjacent commerical Sauget Toxic Dump were operated during the same time periods by the same operator, concern was raised that toxic materials including drummed waste were also possibly dumped in the municipal landfill.

The location and distribution of massive iron metal within the landfill (which may be representative of buried drums) was required as a preliminary portion of this overall investigation of the site by EPA and E & E.

OBJECTIVES

Technos was contracted to make a geophysical investigation of the site for locating buried drums within the landfill. A two phase approach was conducted whereby the three techniques, radar, electromagnetics and magnetics were evaluated on site in Phase I to determine the best approach for locating drums. Phase II was conducted using a gradiometer magnetometer which proved to be the best of the three geophysical methods for conditions encountered at this site. This technique permits magnetic field distortions (or anomalies) to be continuously recorded on strip charts along traverses across the site to provide virtual complete site coverage.

Comparison of magnetic data from a high sensitivity magnetometer and a low sensitivity magnetometer permitted evaluations of the depth of burial and first order estimates of the number of drums.

METHODOLOGIES AND PRELIMINARY TESTS

PHASE I

Three different geophysical techniques were employed during preliminary reconnaissance tests at the Sauget site to determine the feasibility of the best technique under site conditions. These techniques included radar, EM and magnetometry. Each method has its advantages and disadvantages and susceptibility to nearby cultural interferences and/or soil and landfill materials.

Radar

The radar method is useful for detecting buried drums in relatively homogeneous surface conditions or mapping changes in natural geologic settings. Its use in landfills is less than optimal due to the numerous other dumped materials and the relatively high conductivity of the landfill. A clay cover will also seriously degrade the radar's performance and ability to penetrate more than several feet. See Appendix A for a more detailed description of the radar method.

Four N-S radar traverses were made along the eastern part of the Sauget site on lines 50E (center of the gravel road), 25E, 00 and 25W. The location of these lines is shown in Figure 3.

An example of a radar profile is shown in Figure 4 which was acquired along line 25W. Penetration of the radar signals are relatively shallow, being less than 4 feet deep. Numerous shallow anomalies occur between grid stations 270-310 and 360-380. These may or may not represent shallow buried drums or disturbed material in a relatively homogeneous surface section of the landfill. They may be simply "windows" in the surface cover material which allowed radar penetration into the landfill. Without additional information, the meaning of these shallow radar anomalies are inconclusive. Subsequent comparison with magnetometer results indicated that magnetic materials (which the radar did not detect) existed along most of the traverse.

Electromagnetics EM

The EM method is useful for detecting relatively large metallic objects such as several or more steel drums in addition to its primary use in measuring subsurface conductivity. However, in landfills, the presence of many metallic items such as buried cables and pipes, as well as elevated waste conductivities makes evaluation of the EM results difficult in a survey for drums. An EM system with continuous recording capability does provide a much better opportunity locating bulk buried metal by permitting the acquisition of higher density data. See Appendix B for a more detailed description of the EM method.

Four N-S continuously recorded EM traverses were run along the eastern portion of the landfill on lines 25E, 00, 25W and 50W (see Figure 3).

An example of the continuous EM data is shown in Figure 5 from line 50W. Note the relatively homogeneous response between stations 00-150 compared to the strongely fluctuating responses between station 150-900. These EM signatures are indicative of buried metallic materials, however, little information concerning depth and quantity of materials can be gained from these types of EM responses under these site conditions.

Magnetometer

Magnetometers respond to the strength of the earth's magnetic field at a particular location. Total field magnetometers are subject to large field fluctuations caused by solar variations and the influx of cosmic particles on the earths magnetic field. Local distortions or anomalies in this very large field maybe caused by the presence of nearby ferrous metals such as steel or iron.

Total field instruments acquire data at discrete stations at a moment in time and must be corrected for the changing large field variations by making simultaneous measurements at a base station.

The Technos gradiometer magnetometer, using the fluxgate principle provides a built in nulling or correction technique whereby the differential between two total field sensors are recorded as a continuous read-out, hence no base station is required and no corrections are necessary. This capability permits rapid acquisition of data as the sensor is carried across the survey area. In addition, the effects of nearby fences, railroad tracks, and steel towers are eliminated or minimized permitting the detection of local anomalies and buried ferrous objects. See Appendix C for a more detailed description of magnetometer methods.

Initial magnetometer tests showed that the instrument was not sensitive to the variety of cinders and ash used as cover on the site. MAG lines were conducted along grid lines 00W and 25W (see Figure 2). An example of the recorded magnetic data is shown in Figure 6.

The magnetometer results showed a wide range of magnetic anomalies along the initial traverses, from which intensities and lateral width of signals were used to approximate the location, size and depth of the buried ferrous target(s). These interpretations indicated small to massive quantities of ferrous material.

Conclusions of PHASE I

Tests using radar, EM and gradiometer magnetometer techniques at the Sauget Landfill demonstrated the better overall effectiveness of the gradiometer magnetometer technique to locate buried ferrous objects such as drums. Thus, the magnetometer method was consequently used to survey the complete site.

MAGNETOMETER SURVEY

PHASE II

The magnetometer survey was conducted using a specialized gradiometer magnetometer system. The MAG sensor was kept at constant two feet height above the ground's surface to minimize responses from small near-surface pieces of iron. Sensitivity of the magnetometer was reduced by two orders of magnitude from full sensitivity due to the high concentrations of buried metal at the site.

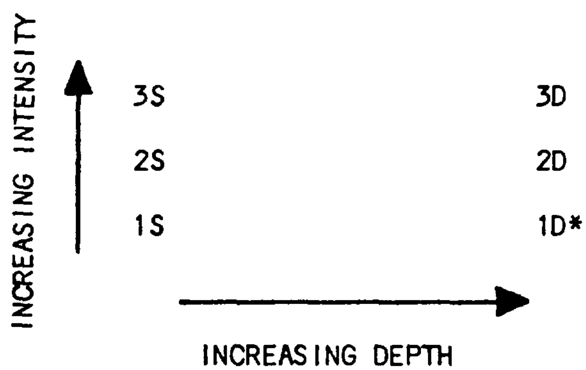
Thirty-three magnetometer traverses, 300-1800 feet in length, were recorded across the Sauget site along parallel lines spaced 12.5 feet apart. These lines were made along the grid lines shown in Figure 2 from 100E to 325W. Seven lines were conducted perpendicular to the long grid axis at E-S stations 400, 600, 700, 800, 1200, 1500 and 1800.

The magnetometer results indicate that ferrous targets exist over the entire extent of the landfill west of the gravel access road. A partially buried railroad track was discovered running along the eastern edge of the road (see Figure 2). Magnetic anomalies other than the steel tracks were not recorded east of the gravel road along the levee embankment.

The magnetometer data over the remainder of the site show a wide range of magnetic anomalies varying in intensity and width. The responses ranged from narrow, low amplitude anomalies (typical of small, shallow (1-2 feet) ferrous targets) to broad, high amplitude anomalies (typical of massive, deep (to 25 feet) ferrous targets - see Figure 6).

To provide a semi-quantitative description of magnetic anomalies, a classification system was developed based upon the relative magnetic intensity and depth of the buried targets. Three intensity levels were chosen and designated 1, 2 and 3 (1<2<3). Each level represents a change in intensity by a factor of 2-3. Two depth levels were also assigned to major anomalies and designated shallow (< 5 feet deep) and deep (> 5 feet deep). The 5 foot depth is approximate and may range from 3-8 feet, highly dependent on the size, shape and residual magnetism of the target.

The interrelation of this classification system is shown below:



* Undetectable at the surrounding noise levels at the landfill.

Thus, the smallest magnetic response is 1S and may be indicative of a paint can 1 foot deep whereas 3D is the most massive and may be indicative of a cluster of 50 drums as deep as 25 feet.

Figure 7 is a detailed map showing the distribution of magnetic anomalies over the landfill. Approximate magnetic intensity and target depth (S or D) as described above are indicated on this plot to give the reader a relative understanding of this complex data.

As seen, the greatest concentration of Intensity 2 and 3 anomalies occur in the north-central and western portions of the landfill. Smaller areas of Intensity 2 and 3 also occur in the SW corner in the general area of the Pillsbury railroad spur; other isolated patches occur across the rest of southern portion of the landfill.

The distribution of shallow and deep designated target areas does not appear to show any patterns. There are no indications that large concentrations of iron (drums) were buried in large pits or trenches, although some of the more massive (Intensity 3) anomalies with deep (D) classification may represent as many as 100 drums to a depth of about 25 feet over a surface area of about 25 feet in diameter.

As indicated by the spatial distribution patterns of Figure 7, dumping of large concentrations of iron material appeared to be somewhat sporadic with greater input of these iron materials at specific times during landfilling. This pattern of input inferred from the magnetic distribution suggests that the high concentrations of magnetic anomalies are drums; it is unlikely that refrigerators or car bodies were disposed of in such massive quantities at singular points in time.

Observations recorded during this detailed MAG survey showed that many shallow but broad depressed areas of the landfill surface correlated to large magnetic anomalies. A wet low area along the central portion of the western fence line (see Figure 2) likewise showed large anomalies. Crushed drums were observed in a nearby fill embankment to the east of this low area.

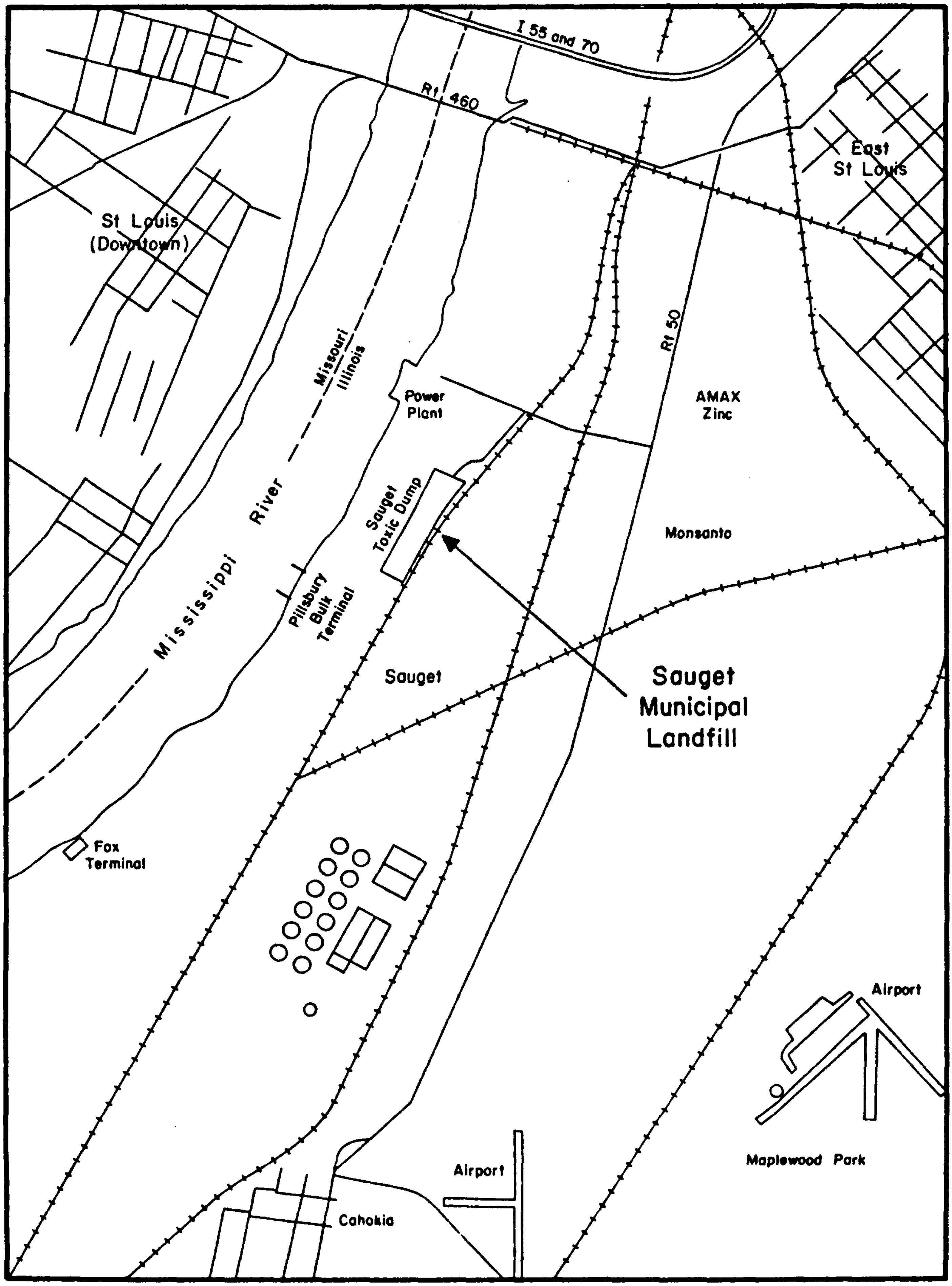


FIGURE 1. General Site Map

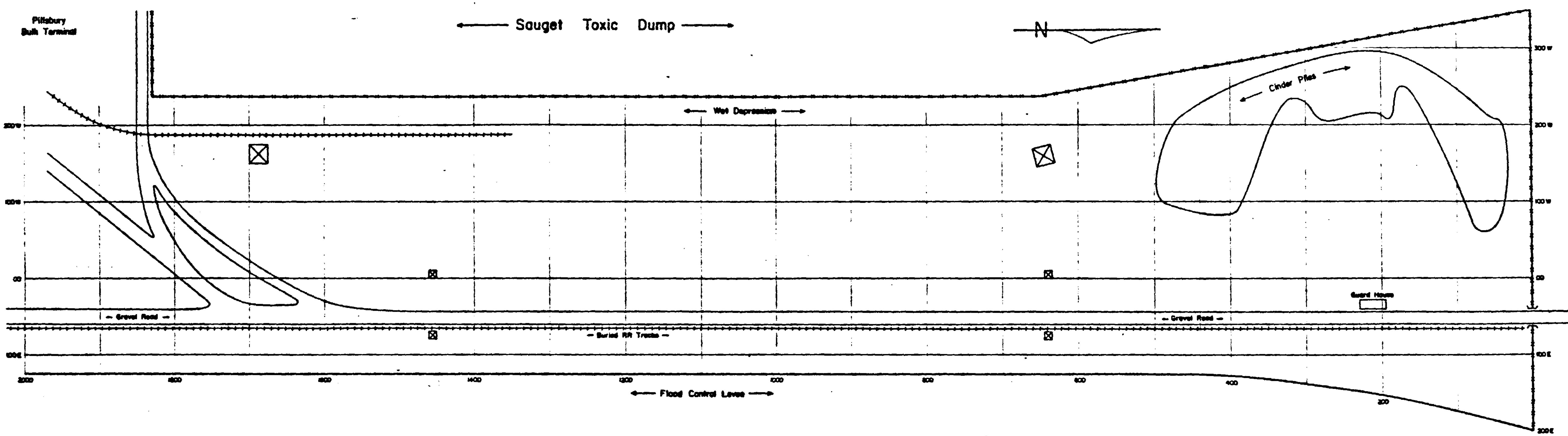


FIGURE 2

DETAILED SITE MAP

SAUGET MUNICIPAL LANDFILL

SAUGET (EAST ST. LOUIS), ILLINOIS

BARBED FENCE
CONCRETE LEVEE
HIGH TENSION LINE TOWER
GRIDLINE 100 FT. WEST (OF CENTER LINE)

0 100 FEET
SCALE

TECHNOS INC

JUNE 1983

MIAMI, FLA

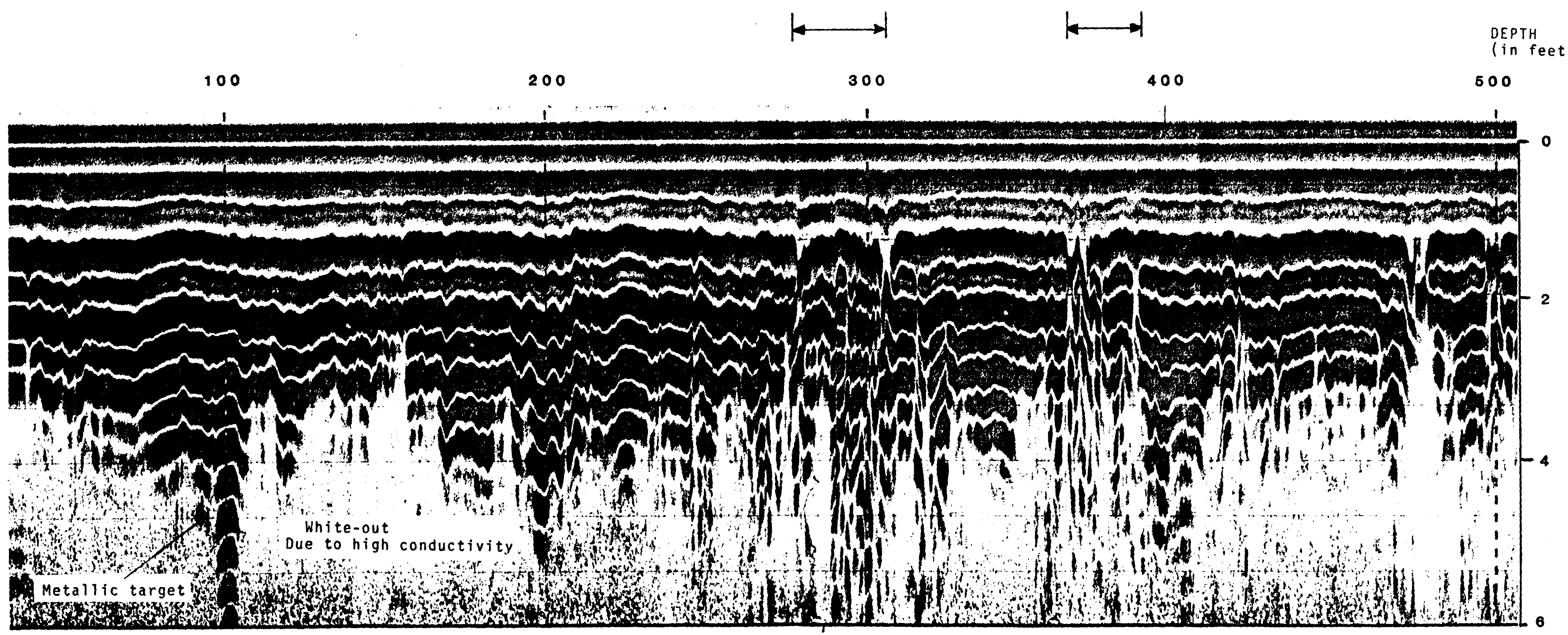


FIGURE 4. Example Radar Profile Line (25W) using 80 MHz Antenna.
This northern portion of radar line 25W shows the limited capacity of the radar technique under conditions at the Sauget Landfill. High conductivity at depths greater than about 2-4 feet severely inhibit radar wave propagation causing "white-outs". Individual "windows" of shallow targets protrude through the cover material at stations 270-310 and 360-390. Vertical scale is approximate.

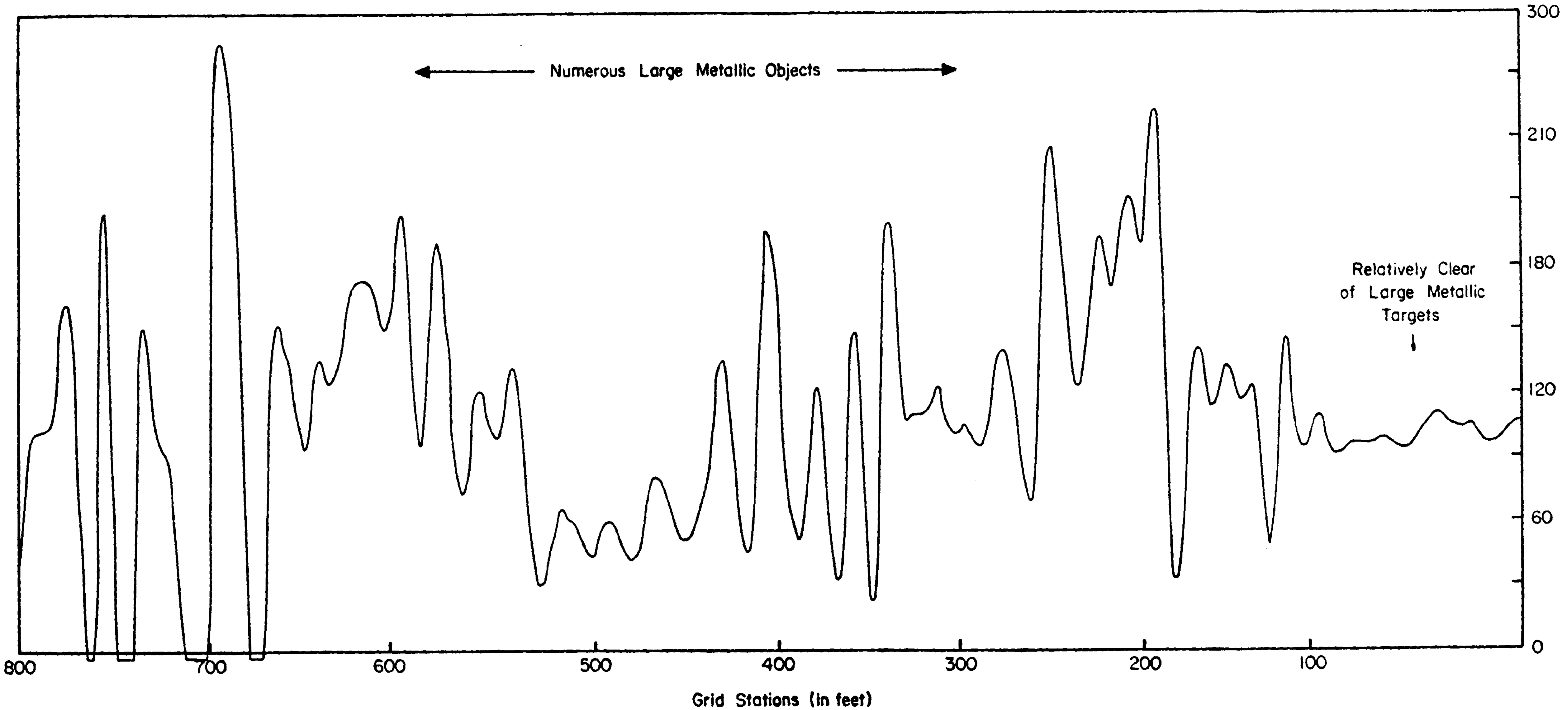


FIGURE 5. Example of Continuous EM Profile Data (50W).
This portion of EM line 50W shows a range of EM conductivities across the northern portion of the landfill. Obvious differences are observed in areas containing large metallic objects versus clear areas. However, the size and depth of such metallic targets can only be very crudely estimated as the EM technique does not have the lateral resolution capabilities of the gradiometer magnetometer.

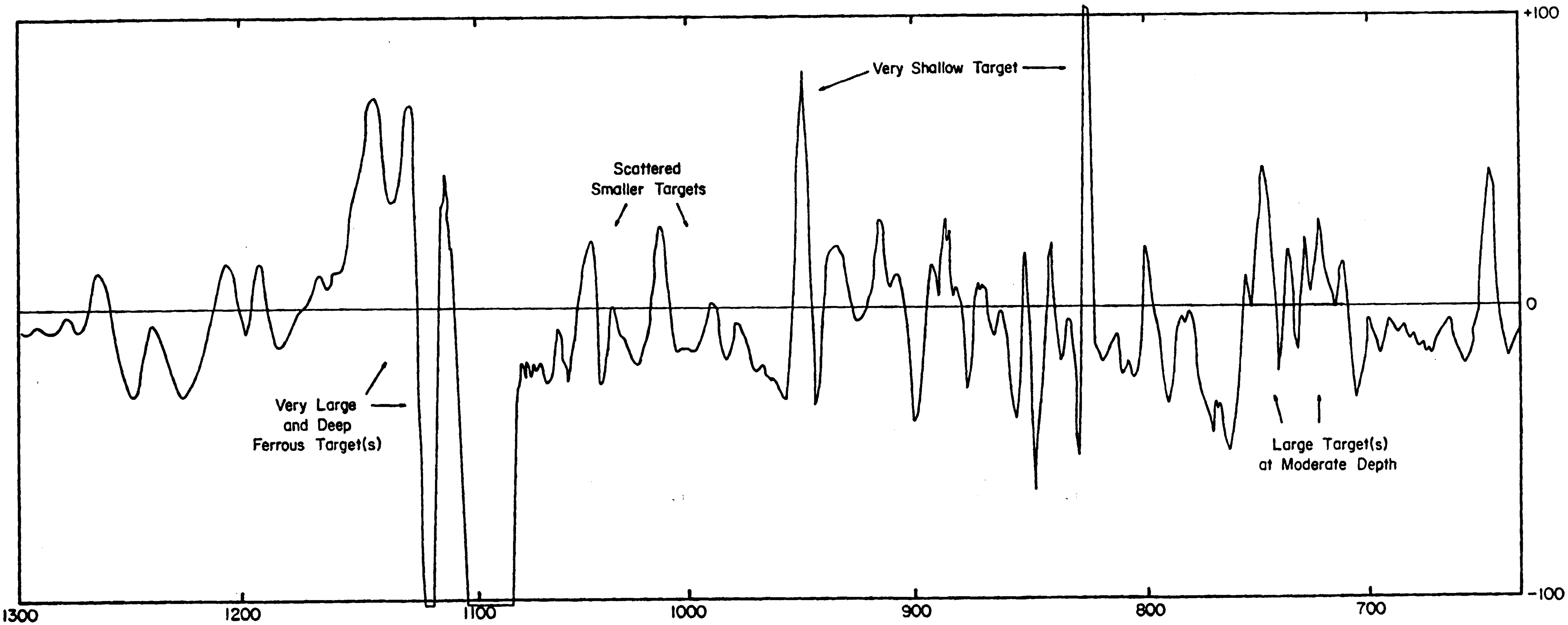


FIGURE 6. Example Magnetometer Profile Data (62.5W)
This portion of mag line 62.5W shows a range of different types of magnetic responses over ferrous targets of various size and depth. Vertical scale is in gradient gammas; horizontal scale is keyed to grid layout shown in Figures 2 and 7.

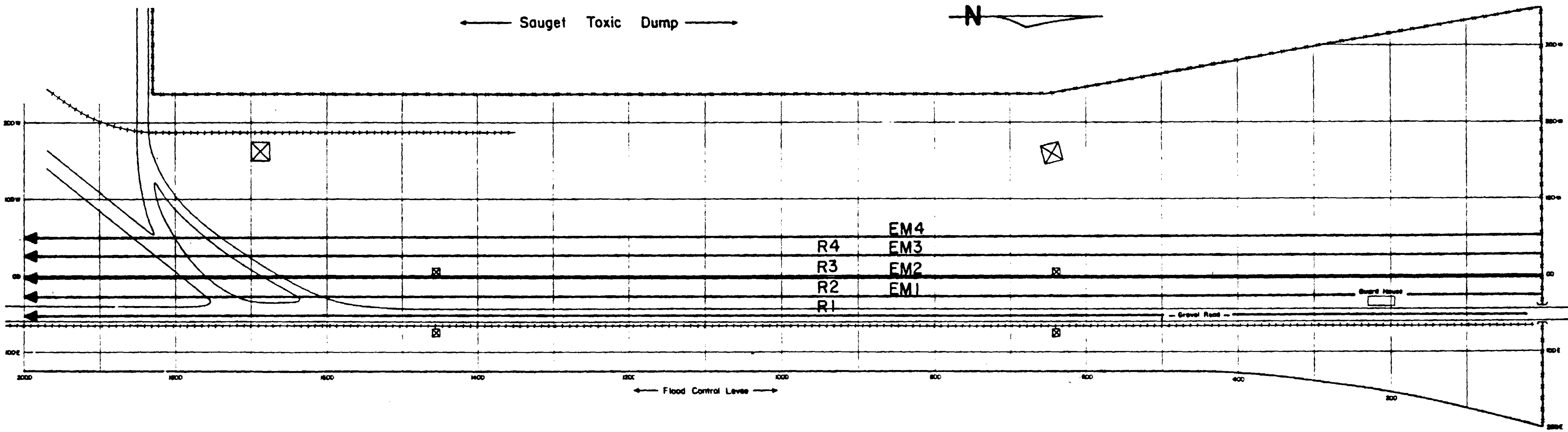


FIGURE 3
LOCATION OF RADAR AND EM TRAVERSES

SAUGET MUNICIPAL LANDFILL
SAUGET (EAST ST. LOUIS), ILLINOIS

BARBED FENCE
CONCRETE LEVEE
HIGH TENSION LINE TOWER
GRIDLINE 100 FT WEST (OF CENTER LINE)

0 100 FEET
SCALE

R1 RADAR LINE 1
EM1 EM LINE 1

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APPENDIX

ELECTROMAGNETICS (EM)

INTRODUCTION

Measurement of ground resistivity is one of the oldest geophysical techniques. Resistivity values result from conditions existing in a large volume of ground which occurs between the system's array or electrodes. The data which are obtained are a function of the site's porosity, permeability, moisture content, specific conductance of pore fluids and other soil and subsurface geochemical parameters. However, the actual values of resistivity for different geological materials and geohydrological conditions are not necessarily diagnostic in themselves; what is of importance is the way in which the resistivity values vary laterally and with depth. This measurement of lateral (or spatial) variations allows the user to detect features as a result of their relative resistivity values and shape rather than their absolute resistivities. Classical resistivity data are obtained by point-by-point measurements which may require an appreciable amount of time to collect a sufficient density of readings.

Electromagnetics (EM) measurements provide similar data as obtained using the resistivity method; these data are called ground conductivities (or reciprocal resistivities). Some of the newer EM techniques are portable permitting data to be gathered as fast as a man can walk. Therefore, the EM method has an advantage over the older resistivity method in that subsurface conductivities (reciprocal resistivities) can be collected rapidly and continuously as the operator and instrument move across the ground's surface.

EM DESCRIPTION

The principle of operation of the EM method is shown in Figure A. The basic instrument consists of two coils and an electronics module. The transmitter coil is separated from the receiver coil by a specified distance. When energized, the transmitter coil induces circular eddy current loops into the earth. The magnitude of each current loop is a function of subsurface conditions. In turn, each of these current loops generates a secondary magnetic field which is proportional to the value of the current flowing within that loop. A portion of this secondary magnetic field is intercepted by the receiver coil and results in an output voltage which is amplified by the instrument. The magnitude of this voltage is linearly related to the terrain (ground) conductivity.

The units of conductivity measurement are millimhos/meter (mm/m). Conversion to resistivity units is as follows:

Ohm-meters = 1000/(millimhos/meter)

Ohm-feet = Ohm-meters x 3.28

EM instruments may be calibrated to read the true subsurface conductivity within a uniform earth. However, subsurface conditions are rarely uniform. In a layered earth where each layer has a different conductivity, the reading will be dependent upon the thickness of the layers, depth of the layers from the surface, and specific conductivities of each layer. The resulting conductivity measurement is a complex function of all these conditions and is called the apparent conductivity. A strict solution for this function requires some knowledge of the layer thicknesses, depths and relative conductivities. However, not all studies need become this involved because first order evaluations may be made by noting the relative lateral changes along a traverse (called profiling). Since data can be obtained as fast as the operator can walk, this profiling capability is a very powerful EM technique permitting large areas to be rapidly surveyed yielding continuous profile lines. These profile data may be recorded on a strip chart and/or magnetic tape recorder. This qualitative method can often describe the location, shape and/or the periodicity of a feature whether it is a clay deposit or a series of fracture zones. Armed with this type of data, along with some ground truth information including knowledge of the local geology, an evaluation of the profile(s) can be made. This analysis results in a more complete understanding of specific features and the overall setting of the site.

TECHNOS INC. uses modified commercial EM systems which include various recording modes, high resolution capabilities, and increased and flexible scale options. Using these systems, continuous profiling can be presently accomplished at three depths: .75 meters, 6 meters, and 15 meters. The .75 and 6 meter systems are man-portable while the 15 meter system is truck mounted. EM conductivity data may also be obtained to greater depths (60 meters) using the point-by-point method.

A number of options are available infield and during post data acquisition and display. Figure B is a block diagram depicting the options possible with the TECHNOS interactive EM system. Figure C shows two data display formats: a single EM profile and a three-dimensional view of eleven parallel profile lines. The 3-D persepective is very useful in mapping general geohydrologic conditions as well as locating and mapping the distribution of anomalous conductivities as often found surrounding hazardous waste sites. In addition, these same data sets can be presented in plan view and contoured to show local and regional trends.

Although the EM technique is ideally suited for profiling, acquisition of vertical changes in subsurface conditions (called sounding) can be accomplished. However, sounding with EM is somewhat limited compared to the resistivity sounding methods. This is due to the fact that only a limited number of discrete depths can be measured using the EM method; this is unlike the variable electrode spacings possible with the resistivity technique. Although the resistivity method may yield more data, it requires more time to make the measurements.

The principal value of EM conductivity data is to provide continuous, high resolution data in an extremely economical manner. This permits reconnaissance investigations to be performed rapidly and effectively in defining the locations and extent of problem areas. EM methods have proven to be vital to geotechnical problems, geohydrological assessments and enviromental studies.

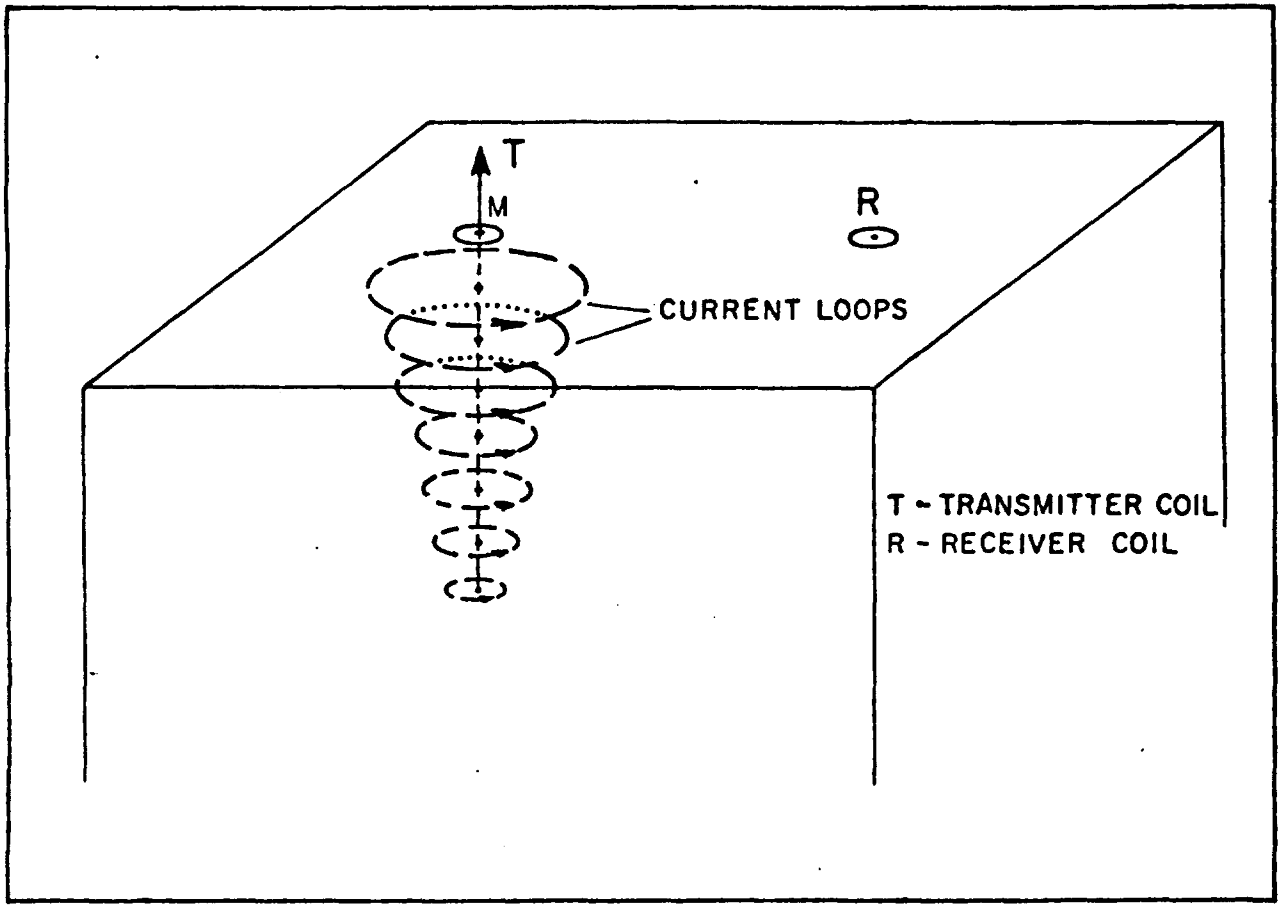

FIGURE A. Character of Induced Current Loops in Ground from EM Transmitter Coil.

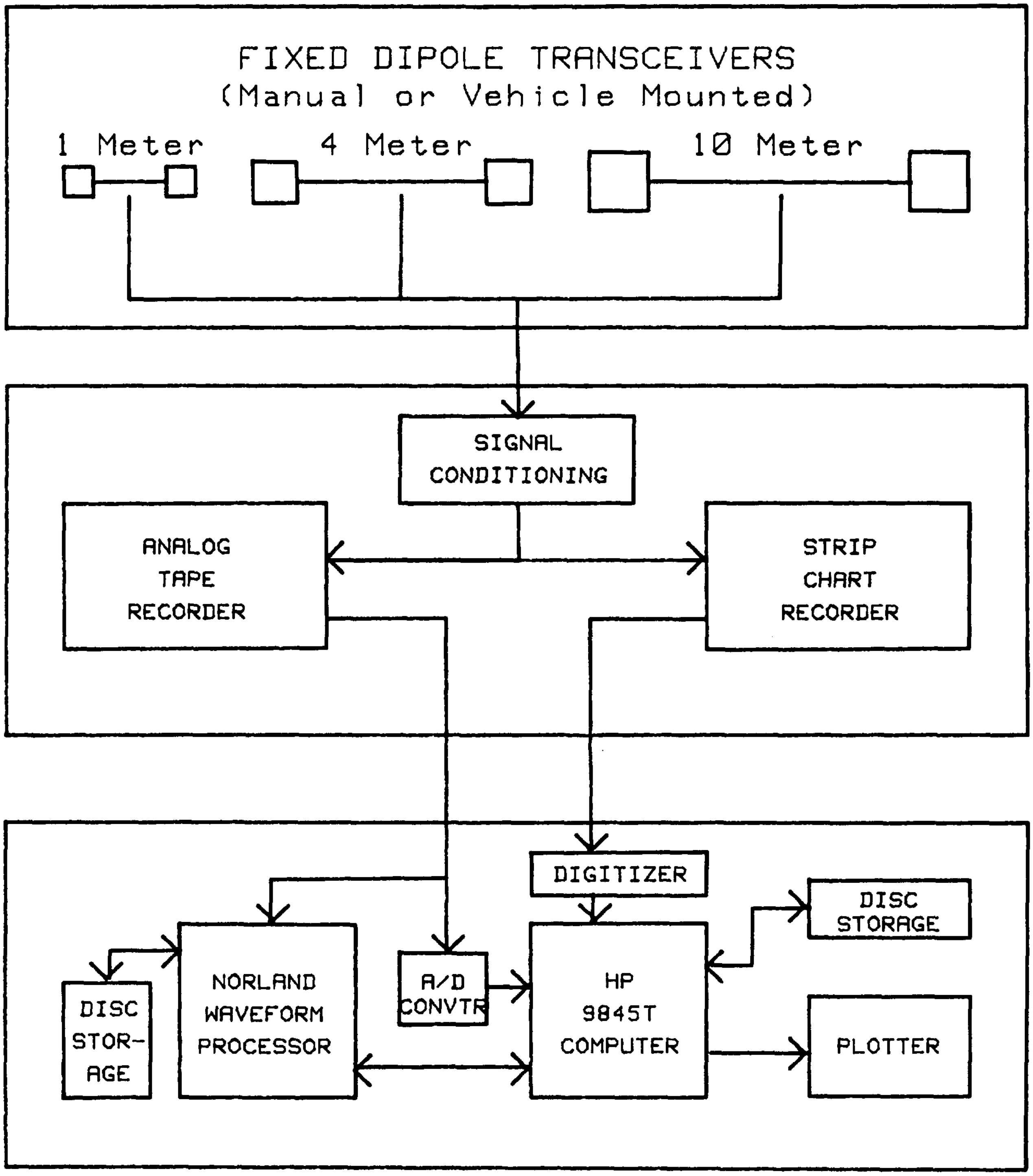

FIGURE 7. BLOCK DIAGRAM OF THE TECHNOS CONTINUOUS PROFILING EM SYSTEM.

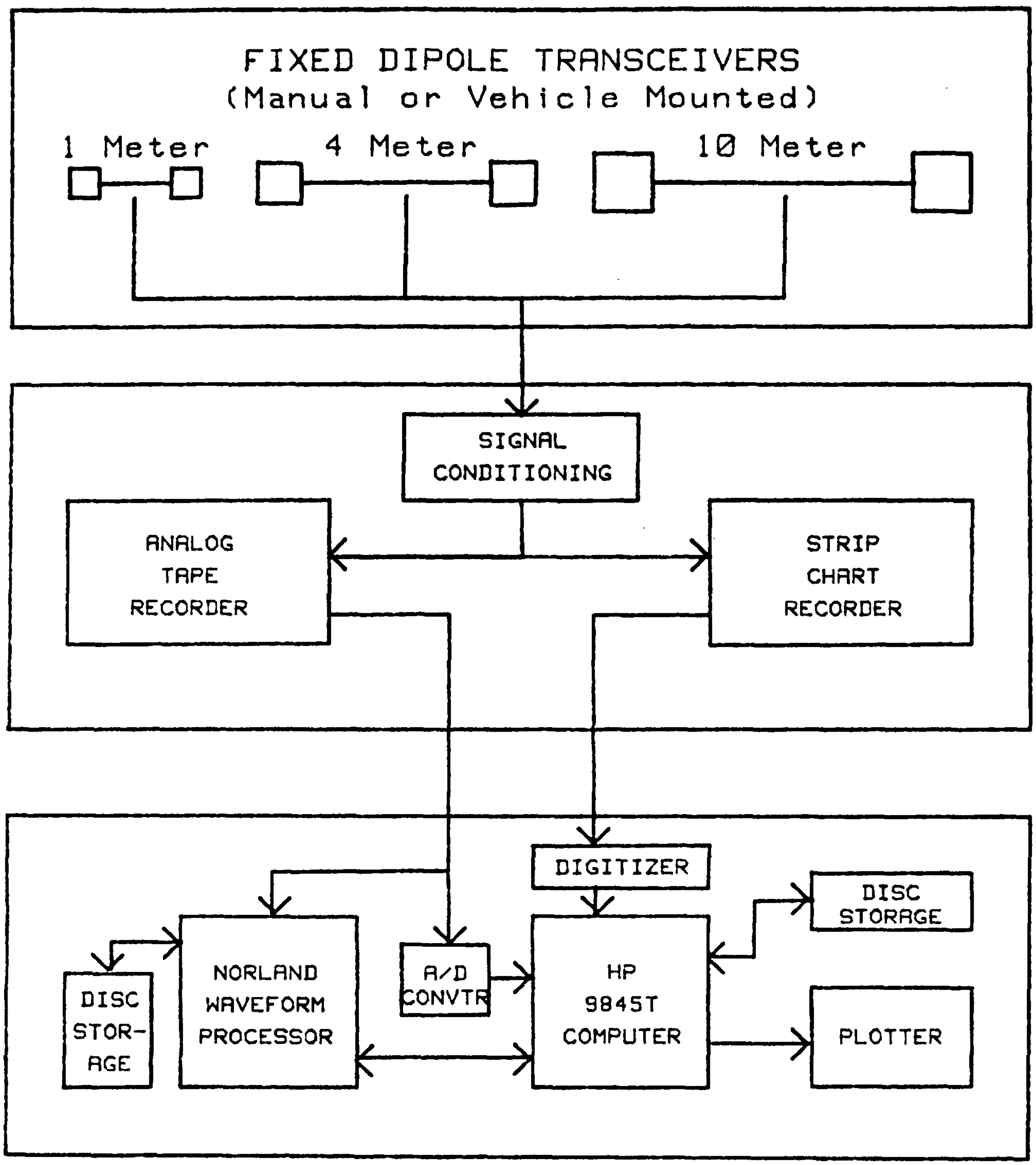

FIGURE B. BLOCK DIAGRAM OF THE TECHNOS CONTINUOUS PROFILING EM SYSTEM.

B

APPENDIX

MAGNETOMETERS

Magnetic field measurements can be used to locate buried ferromagnetic objects such as steel containers or drums, scrap iron and tools. This method is based on the fact that an induced magnetism is produced in any magnetic material within the earth's magnetic field and, if sufficiently large, can be detected as an anomaly in the ambient field. Search magnetometers respond to changes in the earth's magnetic field caused by ferrous metals. Non-ferrous metals do not produce a magnetic response.

The primary factors which influence the response of a magnetometer system are the mass of an iron or steel object and its distance from the sensor. The following list points out the variables which influence the size of a magnetic anomaly:

1) Target mass
2) Target to sensor distance
3) Target material and degree of degradation
4) Target geometry (primarily length to diameter ratio)
5) Target orientation
6) Amount and orientation of permanent magnetism in the target.

Technos utilizes a variety of magnetometers to accomplish various survey objectives. Both total field and gradiometer search magnetometers are available. Proton and cesium systems are used for total field work; fluxgate and cesium gradiometer systems are used for detailed search work. The system commonly used by Technos for most search work is a fluxgate gradiometer built by Technos. This system permits continuous coverage along a line, as opposed to periodic sampling or station measurements obtained with other types of magnetometers. The gradiometer system also permits operation in areas in which a total field instrument will fail to function because of nearby metal fences, pipes and cables. This capability of the gradiometer system is possible since the sensor head used minimizes the presence of horizontal targets such as a steel fence while maintaining full vertical sensitivity for discrete targets below. This system can be carried by hand or can be mounted to a vehicle for covering larger areas.

The basic sensor sensitivity of the Technos gradiometer is one gamma with a system response of .58 gammas per foot over a two-foot vertical gradient. The response of the gradiometer generally falls off as one over the distance to the fourth power for discrete targets.

A secondary (less sensitive) magnetometer is used as a reconnaissance tool to sort out shallow and deeper targets when the instrument is used in combination with a metal detector and other magnetometers. This unit also is a fluxgate gradiometer and is manufactured by the Schonstedt Instrument Company. Its sensitivity is approximately an order of magnitude less than the Technos magnetometer with a gradient of approximately twenty inches, yielding an overall best system sensitivity of ten gammas per foot.

APPENDIX

RADAR SYSTEM DESCRIPTION

The ground penetrating radar (GPR) system is an impulse radar system which operates by radiating short-duration electromagnetics pulses into the ground from an antenna which is in close proximity to the ground's surface. These pulses are reflected from various interfaces within the earth and are picked up by the receiver section of the antenna and returned to the control unit for processing and display (this operation is analogous to that found in acoustic echo-sounding systems). These reflections occur from different soil horizons, soil/rock interfaces, rock/air interfaces (voids), man-made objects, or any interface which has a contrast in its complex dielectric properties. Fortunately, the complex dielectric constant of a material is usually related to physical and chemical parameters associated with bedding, cementation, voids, fractures, faults, intrusions, and man-made structures.

For presentation of data, GPR signals are processed and displayed by a graphic recorder. As the antenna is moved along the surface, the graphic display results in a picture-like record showing a continuous profile along a traverse, very similar to a geologic cross-section found at a roadcut. In this dynamic mode, the antenna may be towed up to 8 KPH (5 MPH) for rapid exploratory work. Detailed studies can be performed by hand towing the antenna at very slow speeds -- 0.40 KPH (0.25 MPH) -- and/or by placing the antenna in a stationary mode at specific locations.

Unfortunately, the depth of radar penetration is very site specific. Depths of 3 to 10 meters are commonly attained throughout the country; 20 meter

Power Supply and Generator

A power supply module supplies the 12-volt power essential for system operation and distributes AC power to the recorder components of the system. The basic AC power for this supply module is provided by a 110 volt, 60 hertz, 120 watt Honda portable generator.

HP 9845B Computer System

The Hewlett-Packard 9845B system is built around a 16-bit micro-computer which has 450 Kbytes of read/write RAM capability. In addition, the main memory is supported with 120 Kbytes of read only memory (ROM) and 1.4 Mbytes of on line mass storage. Peripheral equipment includes a four-color plotter, digitizer, printer and various digital and analog input capability.

The system is small in size and is used in the field when necessary. Existing Technos software permits processing of radar and other geophysical data so that these data sets may be viewed in a number of different spatial plots. This capability, on-site, allows rapid, iterative, interaction with the data to take place in the field. This data may be then further processed for statistical trends and correlation/regression analysis.

The 9845B system is interfaced with the Norland 3001 Waveform Analyzer Computer allowing real-time signal averaging, spectral analysis and storage of discrete radar waveforms and associated analysis results.

Norland 3001 Waveform Computer

The Norland 3001 instrument is a dedicated waveform processing computer. It has the ability to input, display, and analyze one to four signals simultaneously;

single keystroke commands initiate powerful routines such as differentiation, integration, signal conditioning, auto and cross correlations, fast Fourier (and inverse) transforms, power spectral density, transfer functions, etc.

The Norland has been used to identify subtle reflectors in radar waveforms as well as to accurately determine radar signal velocities in various media and determination of complex dielectric constants. Its digital filtering capabilities and stacking have enabled weak cavity and fracture data to be extracted from obscuring noise levels. In addition, it has proven invaluable in radar waveform analysis of hydrocarbons and other contaminants in soil and groundwater. The Norland's abilities are also useful for the reduction of seismic data and detecting periodicities and statistical trends in continuous EM profiles.

INTERPRETATION OF GPR GRAPHIC PROFILE DATA

An example of GPR signal structure and the resulting profile is shown in Figure B. The received signal consists of three basic components. At the top of Figure B1 is the transmitted pulse, or, more precisely, feed-through of the transmitted pulse into the Receiver section that serves as a time reference. Immediately following the transmitted pulse is a strong surface reflection. Then, at the time equal to the pulse travel time from the surface to an interface and back to the Antenna, the interface reflection appears.

The continuous stream of received pulses is fed into the Graphic Recorder and a profile, as shown in Figure B2, is developed as the Antenna is towed along the ground. The Graphic Recorder produces an image by printing strong signals (amplitudes beyond print threshold) as black and weak signals as white. Intermediate signals, such as the noise on the profile between the surface and interface reflections, are in the gray range. The profile is developed as the chart paper moves under the Graphic Recorder stylus and sequential pulses are printed to form a continuous record.

The main feature of the data is the display of dark bands that extend throughout the profile at varying depths. These dark bands are displayed in groups of three closely related bands. These three bands represent the reflection from an interface between two materials. The triple band is a characteristic of the Radar System and is caused by oscillations in the reflection of the pulse.

The vertical scale is initially time-scaled with the travel time of the pulse. This travel time may be converted into a depth scale, if a knowledge of the velocity of propagation in the particular material being surveyed is known. Depth would be calculated by the following relationship:

$$D = \frac{ct}{2\sqrt{\epsilon_r}} = \frac{v_m t}{2}$$

where:

D = depth in feet

c = velocity of light = 3×10^8 meters/sec $\approx$ 1 foot/nanosecond

t = pulse travel time in nanoseconds

ϵ_r = relative dielectric constant of material

v_m = velocity of propagation in material = $\frac{c}{\sqrt{\epsilon_r}}$

The VHF frequency range dielectric constant and conductivity of the earth materials being probed determine the electromagnetic propagation velocity (depth calibration) and the propagation loss (penetration depth) of the GPR system.

To calibrate the GPR data, either the dielectric constant or the depth to a particular interface must be known. The conductivities and dielectric constants of various materials are presented in Figure C. These electrical parameters are dependent upon temperature, pressure, frequency, and impurities. Typical values given in Figure C are for earth materials.

Figure D lists various earth materials and their impulse rate (in nanoseconds per foot two-way travel time). This shows the approximate time that is required for a radar impulse to penetrate the material and be reflected back to the Antenna.

The horizontal scale is dependent upon the speed of the Antenna across the ground and the paper feed rate of the Graphic Recorder. The rate of sampling within the transceiver results in approximately 25 samples/sec. This results in a horizontal spatial sampling of:

17.5 Samples/Ft. @ 1 MPH

8.7 Samples/Ft. @ 2 MPH

4.3 Samples/Ft. @ 4 MPH

Two figures are included to familiarize the reader with radar data as would be obtained in normal survey work.

Figure E shows a soil profile where clean sands overlay a sandy clay loam. The top of the sandy clay loam is clearly visible; it can be seen to vary in depth along the length of the traverse.

Figure F illustrates the results of a radar traverse perpendicular to three buried pipes. Note that when crossing a pipe the response produced by a single pipe is a hyperbola.

Figures G&H are examples of individual radar waveforms as displayed on the Norland waveform analyzer.

penetrations have been achieved under ideal conditions at some sites. This depth is reduced if ground water increases in electrical conductivity, or if there are sufficiently high concentrations of fine grained materials (silts or clays) present. For example, high concentrations of salts, montmorillonite clay or loess are highly attenuative of the radar pulse and penetration may not exceed one meter. It should be noted, however, that a lack of radar penetration or little or no data is often useful information, being most often an indicator of silts or clays or an indicator of a very homogeneous subsurface setting. GPR is an effective tool in saturated soils (freshwater) and may also be used to advantage in shallow fresh water situations as well as in permafrost and ice investigations.

The GPR technique often has applications to problems considerably deeper than its penetration depth. Knowledge of near surface features obtained from the GPR record can provide valuable information on deeper seated aspects of a site. For example, vertical piping can be seen in overlying soils in response to active cavity (sinkhole) development in limestone bedrock at depths well beyond the range of the radar. Deeper exploration can be achieved with this system by using borehole antennas.

The Technos modular radar system is composed of a modified GSSI 4700P Scientific GPR unit which is supported by an HP 9845B Computer System and a Norland 3001 Waveform Processing Computer. In normal operation, all units except the antenna are mounted in a suitable vehicle. The antenna is towed by the vehicle or manually by an operator. The system volume is about 0.34 cubic meters (0.12 cubic feet) with a weight of 123 Kg. (273 pounds). Figure A is a simplified block diagram of the GPR system.

System Description

Control Unit:

The control unit allows the operator to adjust the system for his specific antenna, desired gain, depth window and any other site requirements. This unit then transmits power and a synchronizing signal to the electronics and the pulse generator in the antenna. Subsurface reflections sensed by the antenna are sampled and returned to the control unit via cable as a low frequency signal. Further processing is accomplished by the control unit to provide an optimum signal for output to the graphic recorder and/or magnetic tape deck.

In order to be adapted to a variety of uses, the control system has been designed with many features for maximum versatility. The unit itself has a built-in microcomputer which enables real-time (or playback) processing of the data. Programs available to date for this on-board computer are background removal and filtering.

Antenna/transceiver:

The earth attenuates higher frequency signals while allowing lower frequency signals to be propagated to greater depths. However, it is these higher frequency components that give rise to the resolution of the system (i.e., the ability to discriminate between closely spaced strata or interfaces). Therefore, some intermediate point between these two extremes must be selected. Due to the modular design of the system, a number of antennas (with frequencies ranging from 80 to 900 MHz) may be readily used for maximum flexibility in adjusting to specific site requirements. Units with special characteristics as well as different unit configurations may also be used in addition to standardized antennas. This antenna flexibility is very important since it allows the operator to select the best antenna to match the conditions at hand and achieve desired results.

During system operation a trigger pulse from the control unit initiates a capacitor discharge which drives the transmitter element in the antenna. The transmitted pulse is a quasi-gaussian pulse radiated by a broad band "bow tie" element configuration. This transmitter antenna is in close proximity and electromagnetically coupled to the ground. Whenever the receiver antenna detects a reflected radar pulse (which is travelling near the speed of light), a sampler within the transceiver samples 2000 reflected signals, reconstructing a similar waveform at a much lower audio frequency. This audio pulse is then transmitted through its connecting cable to the control unit in the vehicle.

Surface towed antennas may be either of the monostatic type (one transmitter/receiver element), a fixed spacing bistatic type (separate transmitter and receiver elements in our housing), or the variable spacing bistatic type. The variable spacing antenna configuration enables common depth point CDP measurements to be made. The lower frequency antennas (80 to 150 MHz) are generally of the monostatic or variable spacing bistatic types. They are not normally shielded on the upper side and are, therefore, subject to overhead noise due to trees and power lines. The higher frequency antennas (150 to 900 MHz) are generally of the bistatic (fixed spacing) type. They are commonly shielded on the upper side of the assembly; this is a highly desirable feature when working in a wooded or enclosed area.

These antennas have a fore and aft beam width of approximately 90 degrees inclusive angle while the side beam width is approximately 45 degrees. The pulse repetition rate is 50 KHz with a peak power of 50 watts. In operation the antenna is towed by the equipment vehicle or manually by an operator, being connected to the vehicle mounted electronics by a cable.

Graphic Recorder

The graphic recorder used in the GPR system is an EPC Labs, Inc. Model 2208 instrument. The graphic system accepts the analog signal from the control unit producing a continuous, permanent record on electro-sensitive paper. The recorder is an intensity-modulated device with the sweep of the stylus across the chart paper synchronized with the pulse transmitter trigger. Signal amplitudes above a preset threshold level are printed as black but weak signals remain white with gray scales between them. The paper moves as the stylus is swept producing a graphic profile of any subsurface features below the antenna traverse. Dark bands occur at both positive and negative signal peaks, the narrow white lines being the zero crossover between peaks. Time calibration of the graphic profile is accomplished by driving the system with a pulse generator, resulting in 10 nanosecond bands on the graphic display. Once the relationship between the radar pulse travel time and depth is known, the chart paper may be calibrated in terms of depth.

Tape Recorder

The control unit is capable of outputting analog signals to an instrumentation magnetic tape recorder (Hewlett-Packard, Model 3960) for future processing and analysis. The tape recorder can record profile data up to sixteen times faster than the graphic recorder. This allows much more data to be gathered in the field in a given amount of time. Then at a later time, the data may be played back into the control unit for output onto the graphic recorder.

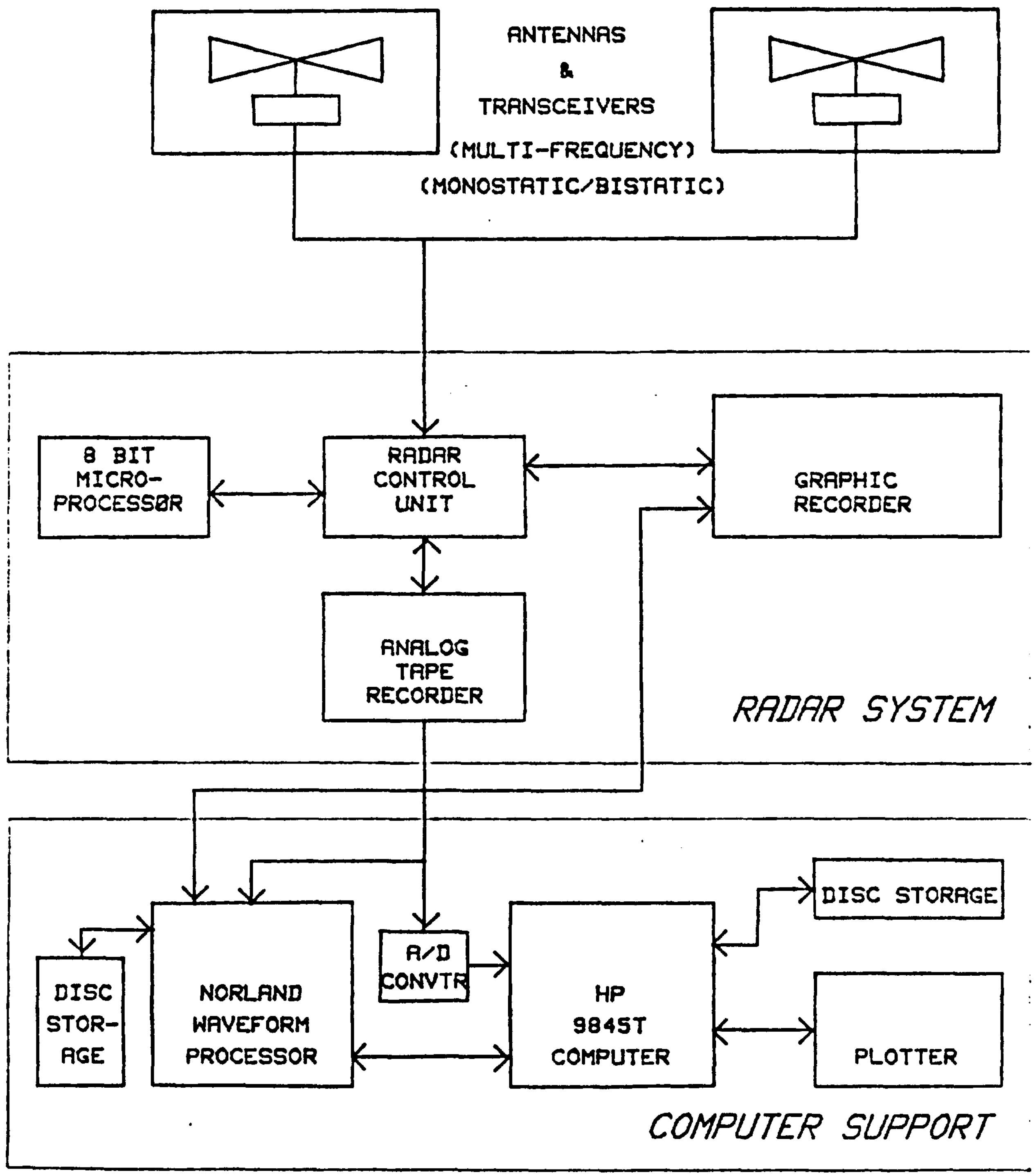

FIGURE A. BLOCK DIAGRAM OF THE TECHNOS RADAR SYSTEM.

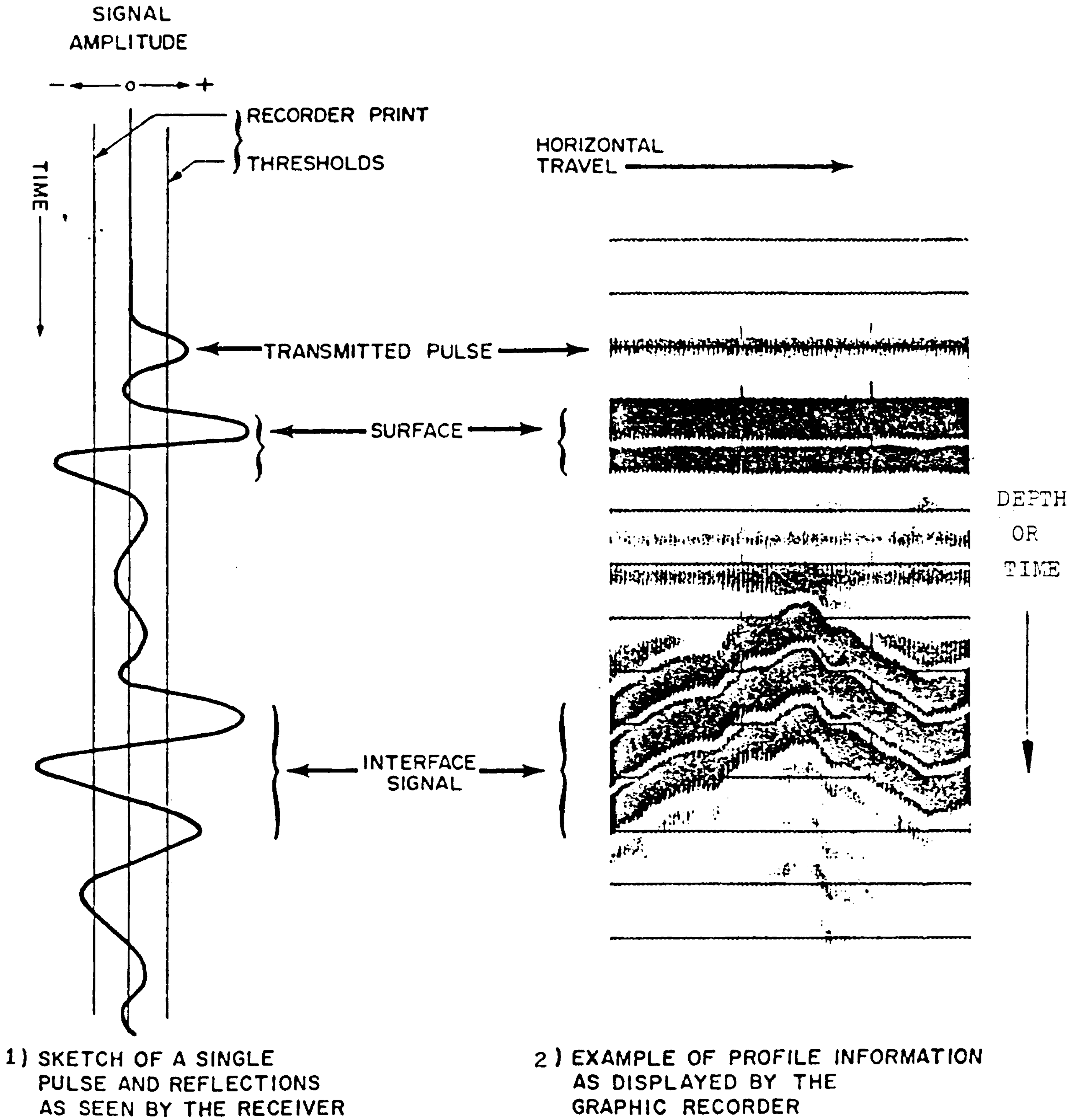

FIGURE 8: EXAMPLE OF GPR SINGLE PULSE AND RESULTING GRAPHIC PRESENTATION

Material	Approximate Conductivity, σ (mho/m)	Approximate Dielectric Constant, ϵ_r
Air	0	1
Fresh Water	10^{-4} to 3×10^{-2}	81
Sea Water	4 to 5	81 to 88
Fresh Water Ice	10^{-4} to 10^{-2}	4
Sea Water Ice	10^{-2} to 10^{-1}	4 to 8
Ice (Glacial)	10^{-6} to 10^{-4}	3.2
Permafrost	10^{-5} to 10^{-2}	4 to 5
Snow Firn	10^{-6} to 10^{-5}	1.4
Granite	10^{-9} to 10^{-3}	8
Sand, Dry	10^{-7} to 10^{-3}	4 to 6
Sand, Saturated (Fresh Water)	10^{-4} to 10^{-2}	30
Silt, Saturated (Fresh Water)	10^{-3} to 10^{-2}	10
Clay, Saturated (Fresh Water)	10^{-1} to 1	8 to 12
Average "Dirt"	10^{-4} to 10^{-2}	16

FIGURE C: CONDUCTIVITIES AND DIELECTRIC CONSTANTS OF VARIOUS EARTH MATERIALS

Material	Impulse Rate (ns/ft)
Air	2
Fresh Water	18
Sca Water	18 to 19
Fresh Water Ice	4
Sea Water Ice	4 to 5.7
Ice (Glacial)	3.6
Permafrost	4 to 4.5
Snow Firn	2.4
Granite	5.7
Sand, Dry	4 to 4.9
Sand, Saturated (Fresh Water)	10.9
Silt, Saturated (Fresh Water)	6.4
Clay, Saturated (Fresh Water)	5.7 to 7
Average "Dirt"	7 to 9

FIGURE D: APPROXIMATE IMPULSE RATES FOR VARIOUS EARTH MATERIALS (TWO WAY TRAVEL TIME)

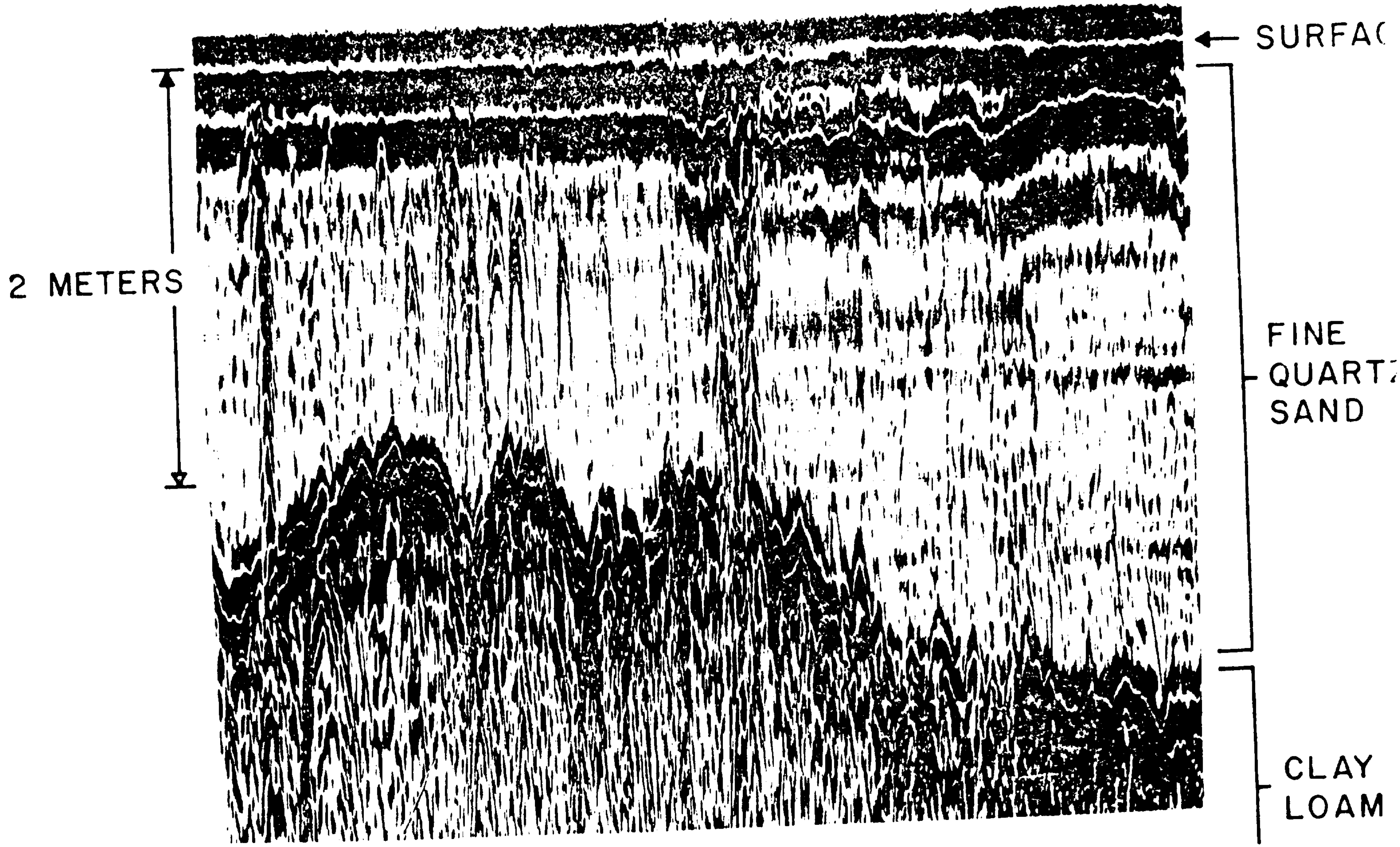

FIG E RADAR PROFILE RECORD OF CLAY HORIZON

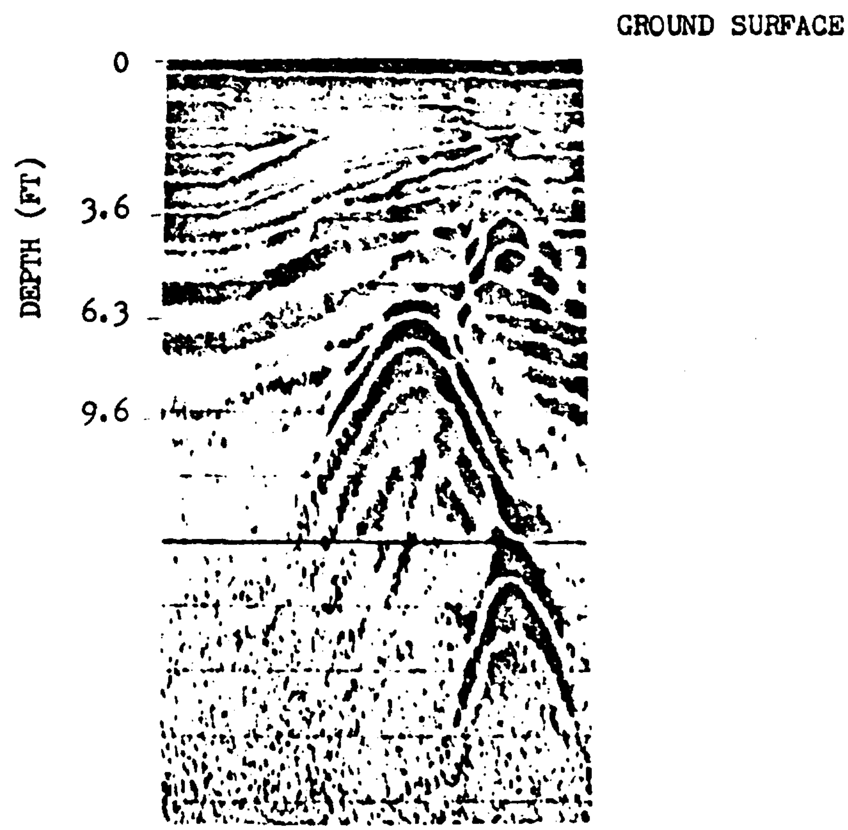

FIGURE F: THREE PIPES IN SAND (NOTE THREE HYPERBOLAS)

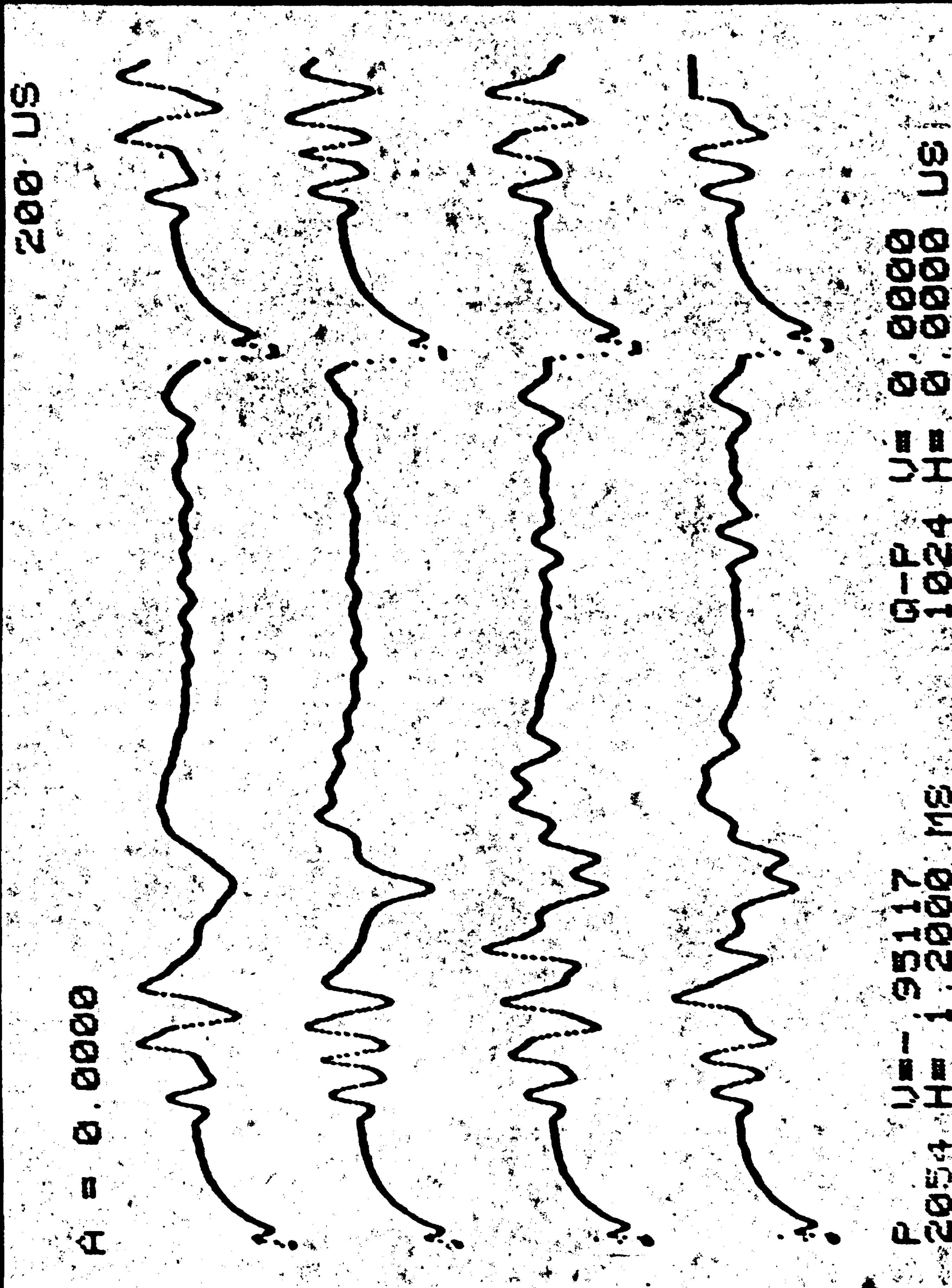

FIGURE G: COMPARISON OF FOUR DIFFERENT RADAR WAVEFORMS AS SEEN ON THE NORLAND WAVEFORM ANALYSER

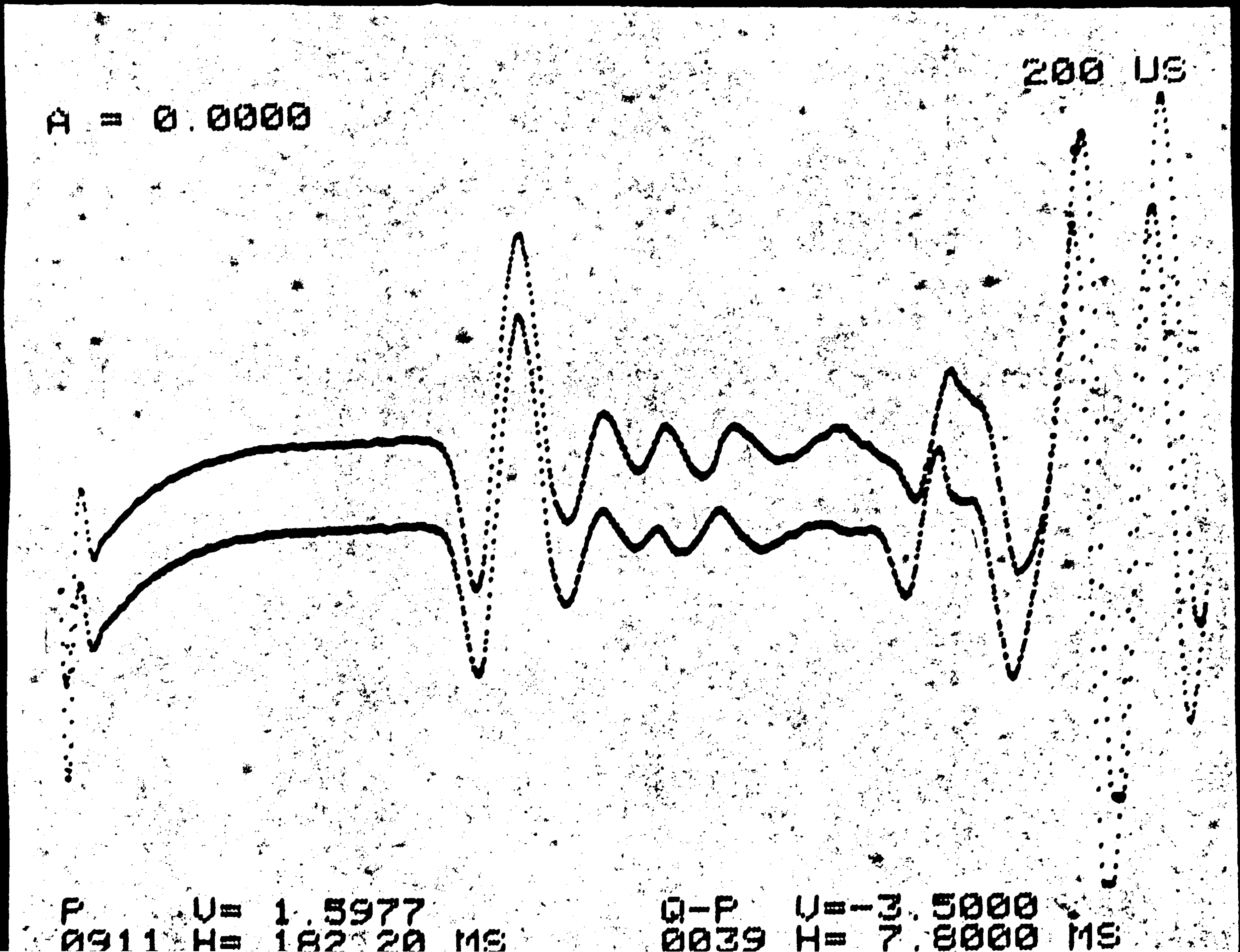

FIGURE H: COMPARISON OF TWO SIMILAR WAVEFORMS ON THE NORLAND WAVEFORM ANALYSER

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FRC #692 **DISTRIBUTION MAP OF MAGNETIC ANOMALIES** **OVER LANDFILL**

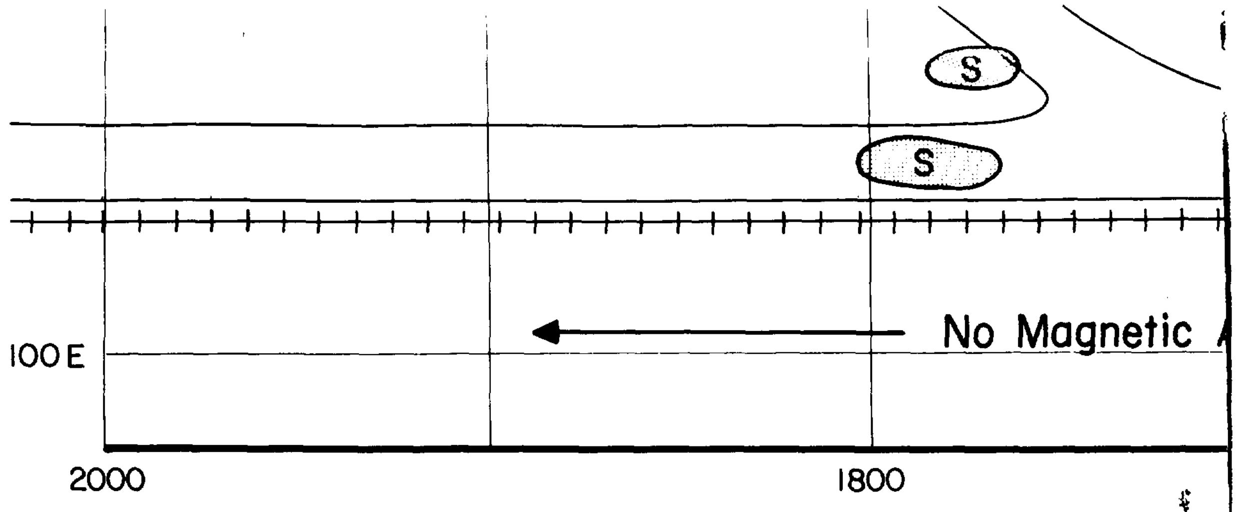

FIGURE 7

DISTRIBUTION MAP OF MAGNETI

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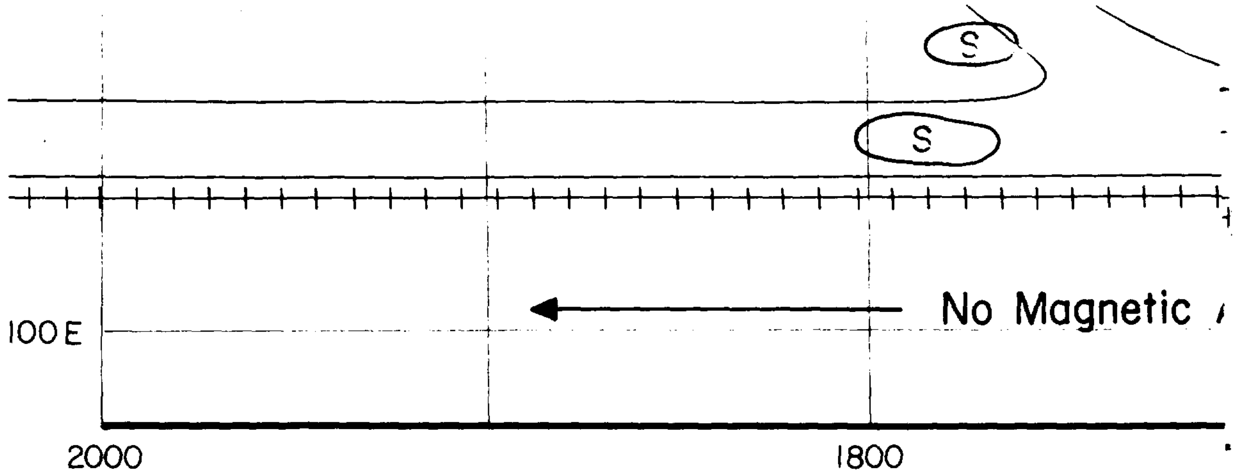

FIGURE 7

DISTRIBUTION MAP OF MAGNETI

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